FUTURE SURFACE COMBATANT CHEMICAL AND BIOLOGICAL WARFARE PROTECTION

Dr. Daniel Driscoll and Mr. Robert A. Fitzgerald, Jr.

The surface combatant of the future must be fully capable of surviving and operating in a chemical and biological warfare (CBW) environment. In order to function in this threat environment, a surface ship must have a full suite of individual and collective protection systems, real-time hazard assessment, multitiered CBW standoff and point detection systems, postattack monitoring systems, and self-decontamination capability—all operated at reduced manning levels. These systems must be highly automated and integrated with a joint warning and reporting network (JWARN) to obtain maximum benefit from this integrated systems approach. These needs are being addressed through the Naval Surface Warfare Center, Dahlgren Division's (NSWCDD's) leadership in both Navy-specific and joint programs.

BACKGROUND

In recent years, there has been a growing awareness that the end of the Cold War in no way reduced, and in some ways may have even increased, the likelihood of use of chemical and biological weapons by countries or organizations hostile to the United States and its interests. Navy forces must operate in a variety of missions where they are forward deployed in the littoral waters of countries or regions where unrest is occurring. U.S. Navy experience in Operation Desert Storm highlighted the increased risk that Navy forces have of encountering chemical and biological agent contamination. Department of Defense guidance[1-3] policy and OPNAVINST S3400.10E require deployable U.S. Navy surface ships and high-threat overseas shore installations to be provided with chemical, biological, and radiological (CBR) defense capabilities. CBR defenses must include a multilayered chemical and biological detection suite consisting of: (a) intelligence, (b) standoff detection capabilities to map and warn of hazards to allow ship avoidance maneuvering and activation of shore-based (CBR) defense systems, and (c) onboard detection and monitoring of exterior areas and interior compartments. The surface combatant of the future will be expected to execute a range of missions in the littoral environment while being capable of surviving and fighting in a chemically and/or biologically contaminated battlespace. These missions have increasingly come to include operations other than war (OOTW), which include noncombatant evacuation operations, or peacekeeping and other limited-conflict missions where the rules of engagement are very strictly drawn. In such operations, Navy forces can become either the direct target of chemical and biological weapons or the unintended downwind recipients of contamination from an area where these weapons are being used.

Besides the OOTW scenarios, the surface warship of the future must also be prepared for the eventuality of a major theater war; where chemical and biological weapons are but one of the threats that the ship might confront. Chemical and biological weapons can be dispersed by bombs, missiles, artillery, spray tanks, or—particularly for biological weapons, by clandestine means. Thus, in major theater war and OOTW scenarios, the chemical/biological threat can be encountered at any time—without warning.

DISCUSSION

The response of the United States to the threat posed by chemical and biological weapons continues to be that our armed forces will continue to fight and win despite the use of these weapons. In general terms, the measures taken can be classified into active and passive defense postures. Active defense postures involve preemptive or counterstrike technology to deny the enemy the use of his weapons. This is accomplished via surveillance technology to acquire targets such as storage bunkers or production facilities, and weapons such as hard-target, smart-fuse warheads tailored to eliminate these sites while limiting collateral damage and loss of life.

A passive defense posture involves having the capability of absorbing a chemical/biological strike and continuing to fight. This is accomplished through the use of an integrated suite of technologies including: hazard assessment and prediction, detection, warning and reporting, decontamination, and individual and collective protection.

Hazard Assessment

Modeling and simulation has been applied with some success for predicting the nature of the hazard presented by chemical and biological agents for a number of missions including shipboard. Models like the "Vapor Liquid and Solid Tracking" model can be used to predict the extent of postattack contamination for any combination of weapons and meteorological conditions. Transport and diffusion of agent vapor and liquid, as well as solid aerosols, are modeled to predict the hazard footprint around a ship or fixed site. This is of great value in predicting the level of challenge that protection systems must withstand and the optimum configurations for deploying detection systems.

Detection

The first line of defense in detecting chemical and biological agents is detection by standoff, or remote means. With detection of the agent at a distance, warning is provided for activating protective measures, and/or maneuvering to avoid contamination. Point detection, on the other hand, detects agents that are present in the immediate vicinity of the ship. Point detection performs two functions. A sensitive point detector sampling air outside of the ship (or a protected shelter) can provide an alarm before the agent reaches a level where it can cause casualties, and it can provide an all-clear indication when the agent threat has dissipated. Handheld portable detectors can be used to survey the extent of contamination and the effectiveness of decontamination efforts (postattack monitoring). These considerations of concept of operations apply equally to both chemical and biological weapons; although in most instances, the detection technologies are not the same for both types of agents.

Chemical and biological detection systems currently in development or entering production for the fleet include the following:

- The Joint Service Lightweight Standoff Chemical Agent Detector (JSLSCAD) is a passive Fourier transform infrared (FTIR)-based remote sensing system that operates in the 7–14 micron region of the mid-IR range, which provides standoff detection capability for chemical warfare (CW) agent vapors (see Figure 1).

- The Improved (Chemical Agent) Point Detection System (IPDS) is an ion mobility spectroscopy (IMS)-based system provides point chemical agent detection capability for surface ships, and is readily adaptable to fixed-site shore facilities (see Figure 2).

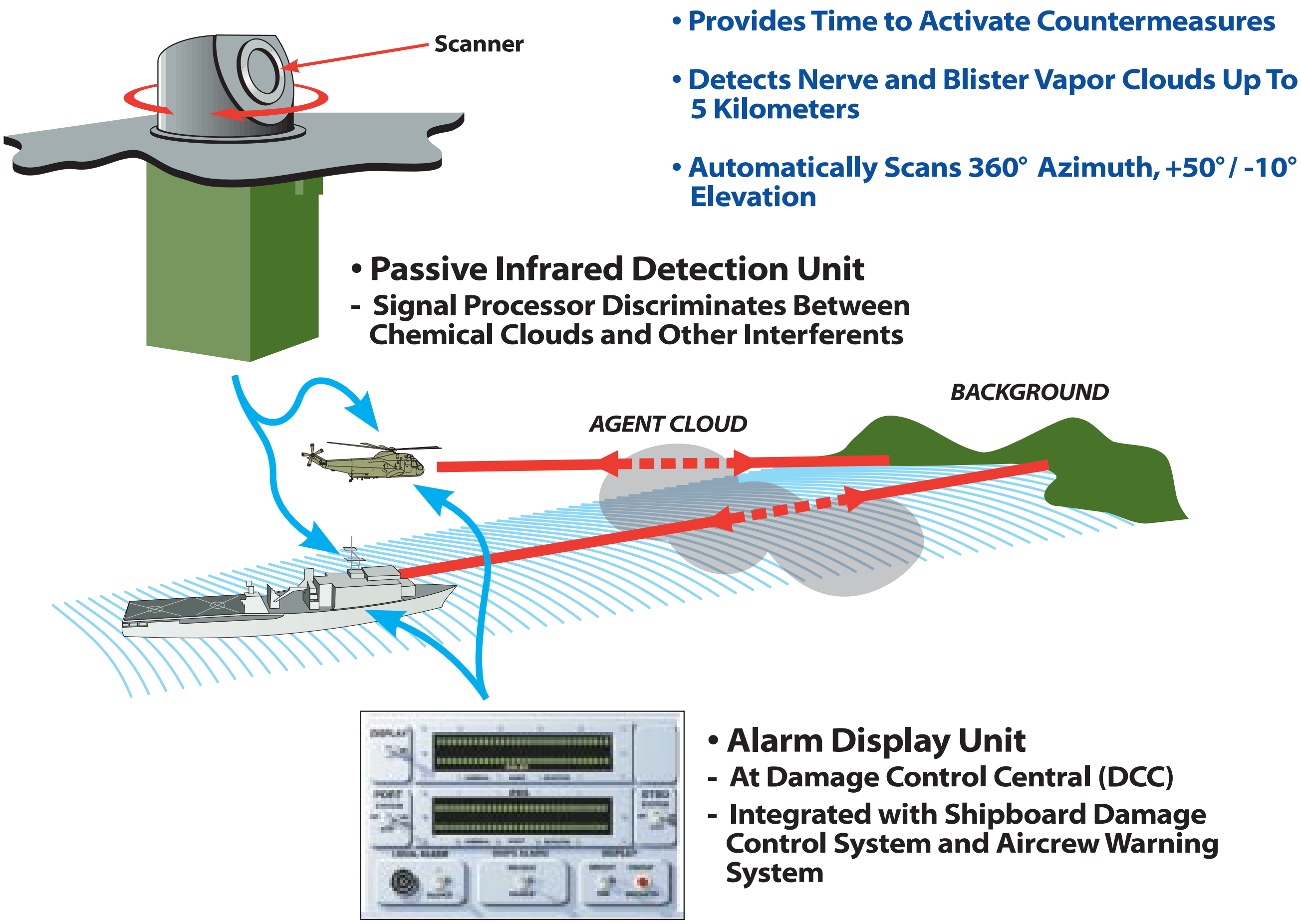

Figure 1—Artist's Concept of Joint Service Lightweight Standoff Chemical Agent Detector (JSLSCAD) System

- The Shipboard Automatic Liquid Agent Detector (SALAD) is a detector for CW agent aerosols (droplets) that is designed as a permanently mounted shipboard system to be operated during heightened CW threat levels. During operations in a chemical environment, the system continuously monitors for the presence of airborne liquid CW agents (see Figures 3 and 4).

- The Shipboard Chemical Agent Monitor, Portable (SCAMP) is a smaller version of the IPDS being developed for portable monitoring and survey missions (see Figure 5).

- The Joint Chemical Agent Detector (JCAD) is a man-portable system using surface acoustic wave (SAW) technology for postattack monitoring (see Figure 6).

- The Interim Biological Agent Detection System (IBADS) has been developed and is installed on selected Navy ships and shore installations.

- The Joint Biological Point Detection System (JBPDS) is the goal of a joint service development effort.[4] Both standoff and man-portable detection of biological agents are the focus of joint service basic research efforts.

- The Joint Biological Remote Early Warning System (JBREWS) is a networked array of point and standoff biological agent detectors that will provide coverage in depth for (large) fixed sites such as ports and air bases.

- The Joint Standoff Wide Area Integrated Laser-Induced Differential Absorption Radar (LIDAR)

Detector (JSWILD) is an active LIDAR standoff detection system for chemical and perhaps biological agents will add mapping and ranging capabilities to standoff detection.

- The Joint Chemical/Biological Universal Detector (JCBUD) is a technology that will fully integrate chemical and biological agent detection in a single package; thereby reducing cost, size, weight, and logistics requirements while continuing to provide protection from both kinds of threat.

For purposes of discussion, detection systems can be divided into two categories; permanently mounted, and man-portable systems. This distinction arises partly from the application of each system and partly from the technology used to accomplish the mission. Figure 4 shows the shipboard installation of SALAD; systems such as SALAD are intended for mounting at a fixed site on the ship and are shielded and mounted in order to withstand the harsh shipboard environment.

Permanently Mounted Systems

The **JSLSCAD** is a passive FTIR-based remote sensing system that operates in the 7–14 micron region of the mid-IR range. The application of the JSLSCAD system to shipboard platforms (see Figure 1) is similar to the ground applications. The major recognizable differences are the more complex system integration and the severe shipboard environmental conditions. Shipboard environments must be specifically addressed with respect to the exposed optical elements of the JSLSCAD scanning

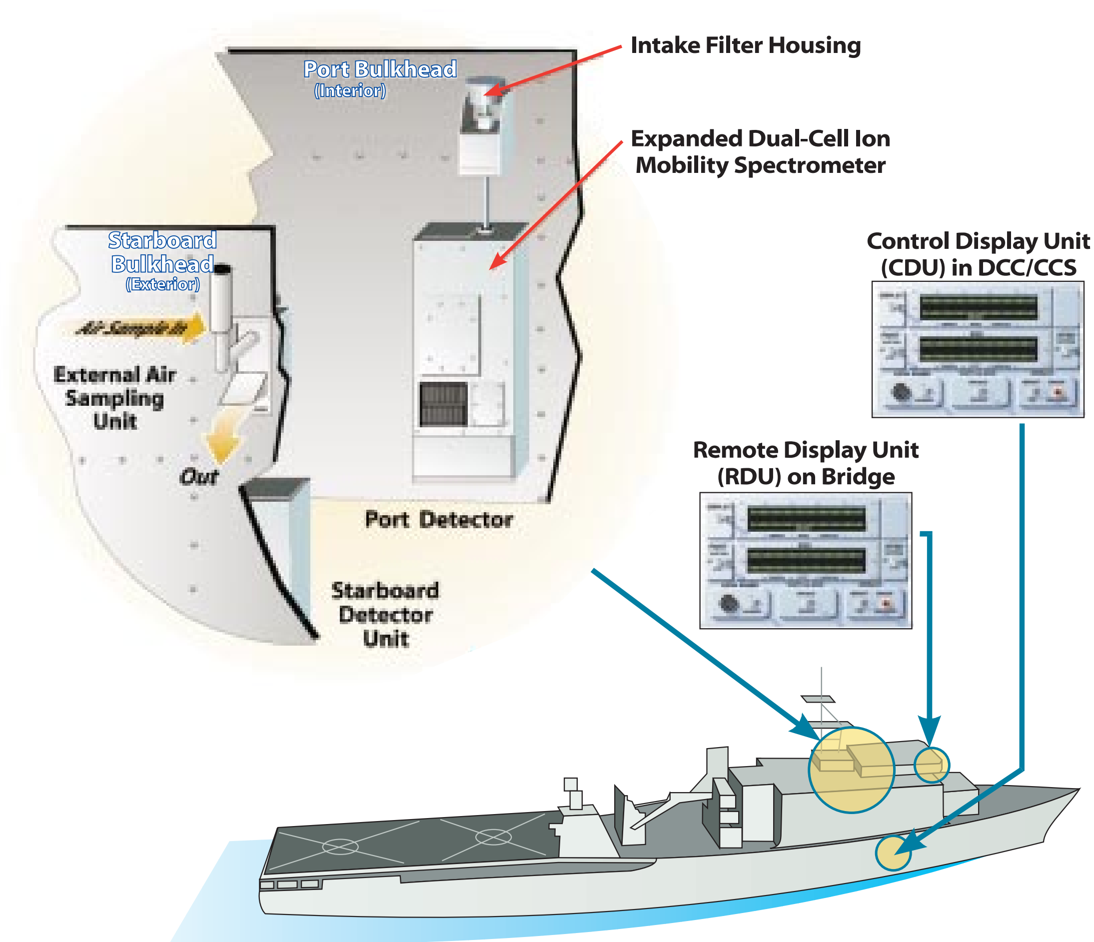

Figure 2—Artist's Concept of the Improved (Chemical Agent) Point Detection System (IPDS)

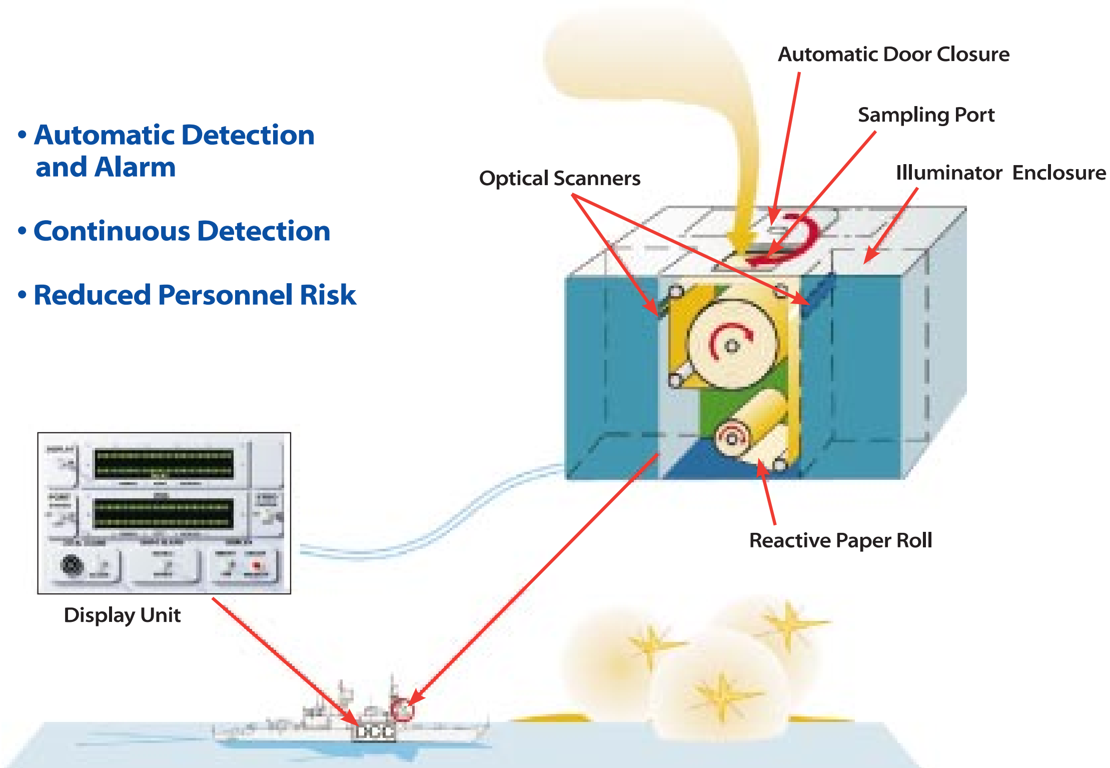

Figure 3—Artist's Concept of the Shipboard Automatic Liquid Agent Detector (SALAD)

Figure 4—Prototype SALAD Detector Unit Installed for Operational Test on *USS JOHN L. HALL* (FFG 32)

system. Furthermore, salt spray and wave action could result in obscuration if the system is not properly protected by design or mounting.

In the shipboard application, the required field of regard (FOR) is 360° in azimuth, and elevation ranges from 10° below the horizon to 50° above the horizon. To accomplish this, the JSLSCAD must be mounted as high as is practical, while still allowing access for maintenance. In addition, a clear 360° viewing angle may not be attainable and may require selective programming of the scanning-function azimuth angles to avoid, for example, a shipboard mast or antenna. Of necessity, this requires a trade-off between the FOR and a practical topside location of the sensor; time to alarm also benefits from reducing the extent of the FOR. As for the azimuth range, for certain missions it may be acceptable to run a 180° azimuthal search.

The IPDS is a dual-cell IMS chemical-agent point detection system. Each system (see Figure 2) consists of

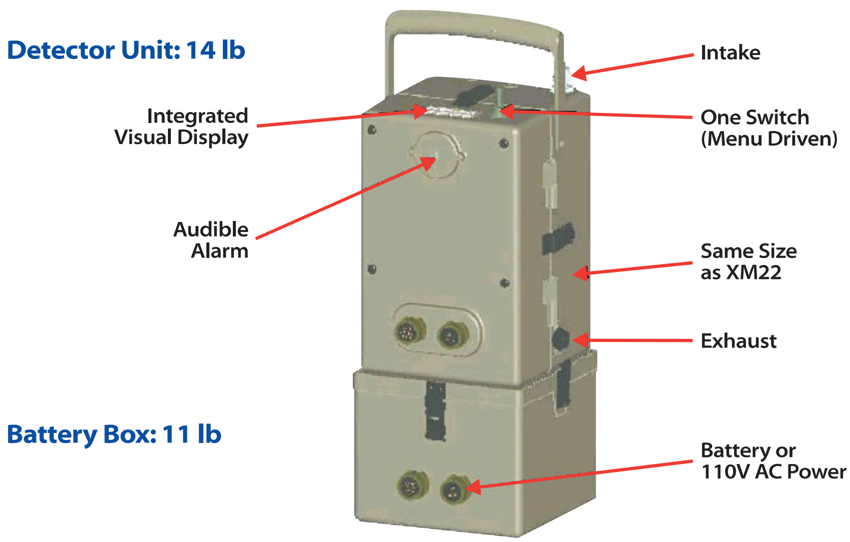

Figure 5—Artist's Drawing of Shipboard Automatic Chemical Agent Detector and Alarm (Ship-ACADA)

two detector units (DUs), typically mounted port and starboard, coupled to an external air sampling unit (EASU). The system is controlled by a remote control display unit (CDU), which displays detector and EASU status, and provides audible and visible alarms for the presence of nerve and blister type CW agents. Each DU contains two IMS cells, which simultaneously analyze air samples from the EASU for the presence of nerve and blister agents. An imbedded signal processor in each DU performs all detection algorithm and control tasks. DU status and alarm messages are sent to the remote CDU, and to a second remote display, allowing the detectors to be monitored from two remote locations. The remote CDU is located in damage control central; the remote display unit (RDU) is located on the bridge. The alarm display units are connected to the 1MC ship's alarm to provide shipwide notification of a chemical attack. IPDS Provides point chemical agent detection capability for surface ships and could be readily adapted to fixed-site shore facilities.

The **SALAD** is designed as a permanently mounted shipboard system (see Figure 3) to be operated during heightened CW threat levels. During operations in a chemical environment, the DU continuously monitors for the presence of liquid CW agents with a specially designed detector paper that stains upon contact with liquid chemical agent droplets. The DU uses spectrophotometry technology to view the sample and, if CW agents are detected, provides digital signals to activate visual and audible alarms at the CDU and RDU. The DU consists of an automatic door that opens when the system is activated, exposing a 4- × 4-in area of detector paper. Inside the DU is a Detector Paper Cassette,

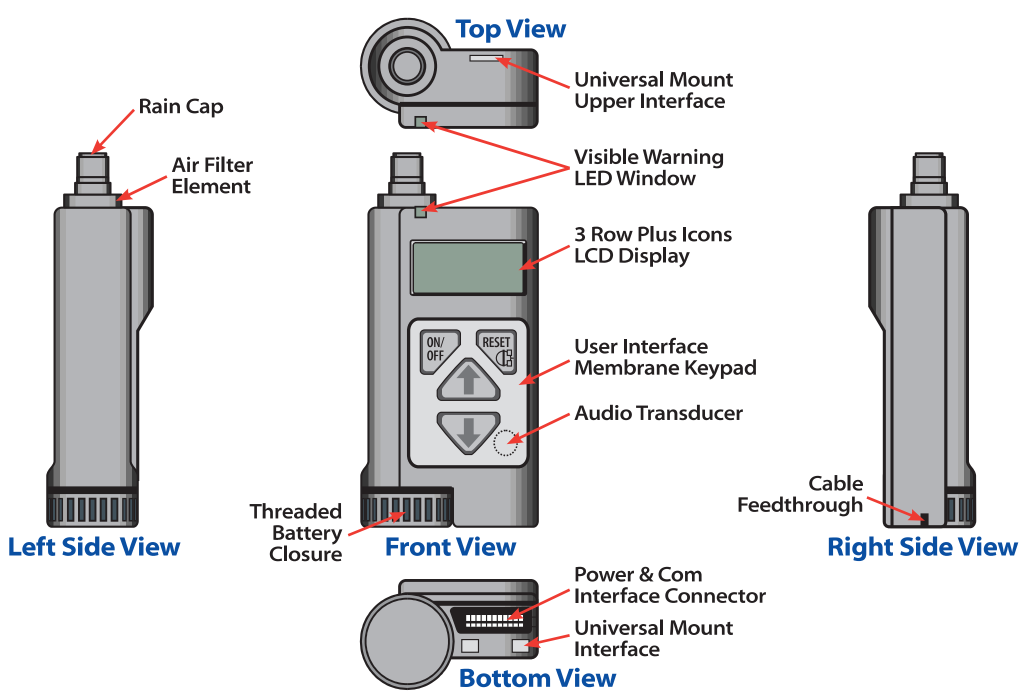

Figure 6—Artist's Concept of Joint Chemical Agent Detector (JCAD)

two Optical Scanner Assemblies, an Illuminator Assembly, and electronics and mechanical hardware that control the operation of the DU. The DU (see Figures 3 and 4) continuously advances the detector paper past a fixed-aperture, exposing the paper to liquid agents falling from the atmosphere. The optical scanners detect any change in the color of the paper, and the detection algorithm then makes agent identification based on the observed change.

The **IBADS** currently addresses the need for biological agent detection on ships pending deployment of the JBPDS. Detection of biological agents is complicated by the fact that they are typically present as aerosols and are much more massive than the vapor emanating from chemical agents. Typically, biological detectors use a two-stage approach. An alarm is set off if particles of the proper size are detected, indicating the possible presence of an agent. Subsequently, a second technology is used to confirm the presence of the agent and identify the specific agent. In the IBADS, an aerodynamic particle sizer acts as the trigger, setting off an alarm when the particle count, in the size range corresponding to biological aerosols, rises above background. A wet sample is then automatically collected, and the sample is (manually) interrogated by an immunoassay using specific antibodies for the agent to make the final identification. JBPDS will be modular in design and employ different analytical techniques depending on application. The shipboard version of this system will, as is the case with IBADS, use a two-stage trigger and identification approach.

The **JBPDS** will, upon entering production, replace the IBADS. Nine different system configurations have been designed for a wide range of platforms. The basic biological detection suite provides detection for all vehicle, ship, and field-mounted and fixed-site applications. Platform-unique kits are used to tailor the system to unique platforms or missions. The basic two-stage approach is still fundamental to the JBPDS basic suite; it also incorporates a handheld immunoassay detector for certain applications.

The **JBREWS** is an array of networked sensors providing defense in depth for large fixed sites such as ports or airfields. A combination of biological point and standoff detectors are employed—combined with hazard assessment/prediction models running in real time—to evaluate evolving threats and, together with meteorology and other data, gauge the credibility of the threat picture both to define the nature of the attack, and reduce the incidence of false alarms.

The **JSWILD** applies a proven technique, known as Differential Scattering and Differential Absorption Lidar. Eye-safe laser light at several different wavelengths is transmitted from a frequency-agile carbon dioxide laser in the 9–11 micrometer region and is differentially scattered and absorbed by CB agents. The detection and analysis of light returning to the lidar system can indicate the presence of biological agents and uniquely identifies chemical agents, since each has a characteristic scattering and absorption spectrum. The use of an active system (lidar) allows for real-time detection, identification, and mapping of chemical agent rain and aerosols—in addition to vapors, as well as detection and possibly some discrimination of bioaerosols—and provides precise range information. This system has been demonstrated to be effective in realistic scenarios from ground as well as airborne platforms at ranges up to 15 km.

Portable Detection Equipment

Postattack monitoring and survey, decontamination, and other specialized missions require portable detectors. This presents a unique set of design constraints distinct from the fixed-point detectors. While the other services have been the technical lead on some of these programs, here (as elsewhere) the unique shipboard environment must be addressed in the system design and testing.

The **SCAMP/ Shipboard Automatic Chemical Agent Detector and Alarm (Ship ACADA)** utilizes IMS (the same technology as the IPDS) and is functionally identical to the detection process used in IPDS. However, by combining those cells in a single housing and replacing all internal tubing with modular manifolds, the IPDS DU has been reduced to a man-portable configuration for compartment and postattack monitoring (see Figure 5). Enhancements to the IMS cell design have improved the detection capability of the SCAMP. The SCAMP is being developed to provide an interim capability pending maturity of the JCAD program.

The **JCAD** Program will develop a handheld postattack monitor for chemical agents based on SAW technology. SAW devices are of two types: delay-line and resonator-type devices. In a delay-line device, the propagation time for SAWs to traverse the device changes with the absorption of molecules onto the surface of the device. The time delay is measured for each event. In a resonator, a standing acoustic wave is established in the device. Absorption of molecules causes a change in the surface modulus, causing a change in the resonant frequency. In this case, the frequency shift is the figure of merit. In the JCAD, an array of resonators are coated with chemically specific polymeric coatings. The frequency shifts produced in the array are unique for each chemical agent. A very small pneumatics system is needed to draw samples into the detector, resulting in a system that is very compact. With its small size, and low weight and power-consumption requirements the JCAD is a convenient handheld device (see Figure 6).

Individual and Collective Protection

Protection technologies fall into two distinct categories: individual and collective protection. Individual protection covers all equipment required to protect the warfighter who must carry out their mission in a contaminated environment, including, gas masks, protective outer garments (suits), boots, and gloves. Collective protection provides a contamination-free environment in which personnel can work or rest without the encumbrance of individual protective gear. Collective protection can be provided for shelters, buildings, and interior spaces of vehicles and ships.

Collective Protection

All surface combatants under construction beginning in 1992 have incorporated the Collective Protection System (CPS) in their design (see Figure 7). Depending on vessel size, between one and four collectively protected zones are provided for each ship. Within each zone, the atmosphere is maintained at positive pressure relative to the outside ambient air. Air is pumped into the zone through two-stage, high-efficiency particulate air and activated charcoal filters so that any contamination in the ambient air is filtered out prior to the air's being pumped into the protected zone. Besides providing protection from chemical and biological contamination, this also provides clean, dust-free air. There is also a program to backfit collective protection onto selected ships and buildings. The Selected Area CPS is a modular design that can be mounted on a ship's hull to provide protection to selected spaces in the ship.

The general concepts outlined above are being applied to the specific mission of permitting the surface combatant ship to fulfill its mission in a chemically and biologically contaminated environment.

Individual Protection

The **MCU-2A/P Protective Mask** provides eye and respiratory protection from all chemical and biological agents, as well as radioactive particulate material. The mask uses a replaceable, standard NATO filter canister mounted on either side of a wide-view, optical-quality visor. The mask provides improved fit, comfort, and visibility relative to earlier masks, and includes a drinking tube for attachment to the standard canteen and a voice-emitter for improved communications.[5]

The **Chemical Protective Overgarment** protects the wearer against all known chemical and biological agents presenting a percutaneous hazard. The suit consists of a smock and separate pair of trousers, sized to accommodate the 5 percentile female through the 95 percent male ratio. Navy-wide replacement of this garment began in calendar year 1997 by a superior suit developed under the auspices of the Joint Service Lightweight Integrated Suit Technology Program. The resultant new Mark III chemical, biological, and radiological (CBR) suit

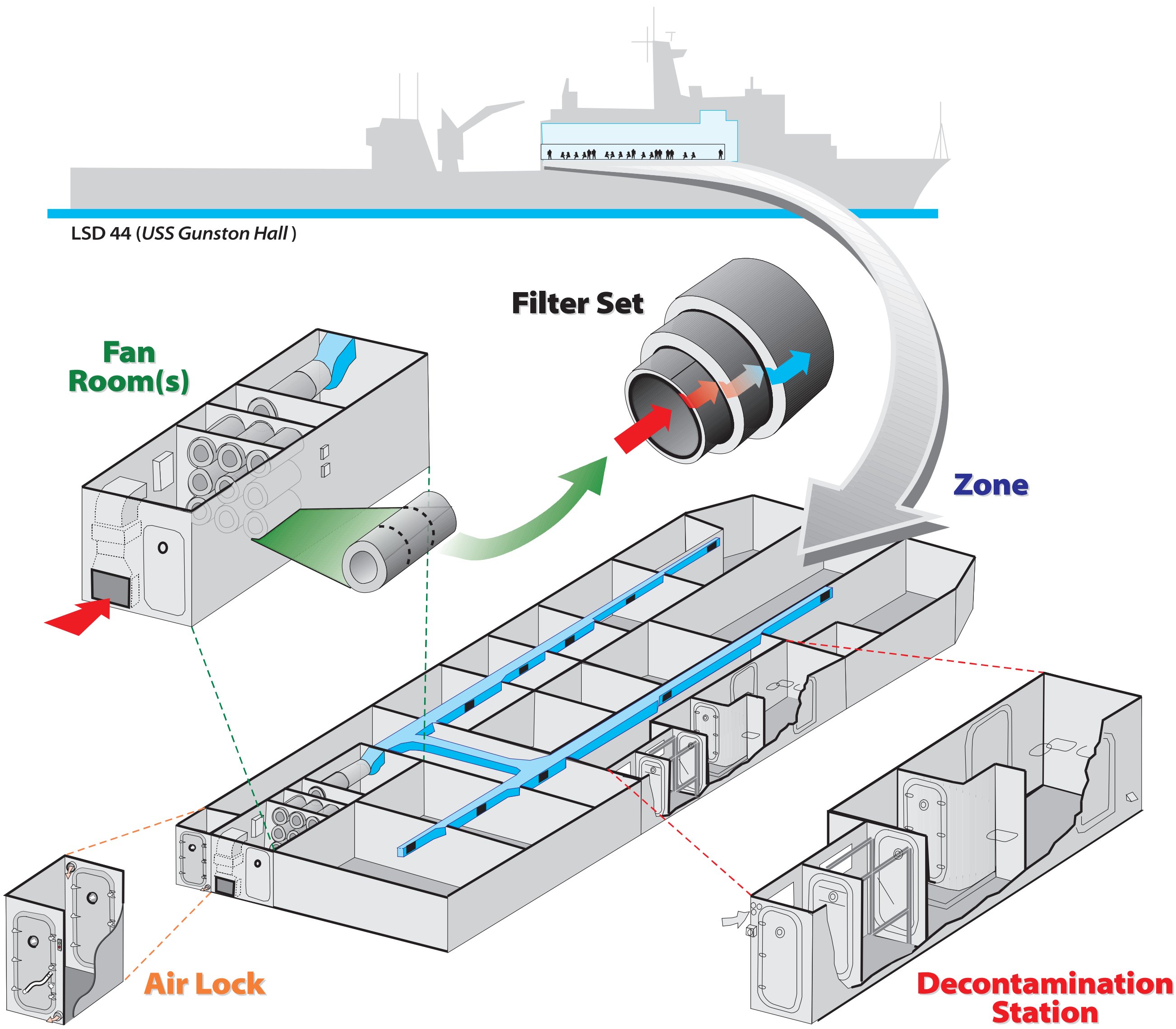

Figure 7—Typical Shipboard Collective Protection System (CPS)

protects against chemical agent vapors, aerosols, droplets, and biological agents.[5]

Decontamination

Decontamination of topside deck and bulkhead surfaces is provided by the ship's countermeasures wash-down system. The countermeasures wash-down system sprays seawater in aerosol form over all exterior surfaces of the ship; this procedure prewets and then rinses topside surfaces with seawater to prevent the agents from adhering to the surfaces, and aids in the removal of chemical or biological agents, if present. Special equipment and personnel decontamination may be done using HTH (bleach) diluted with water.

The **Joint Service Wide-Area Decon** Program is seeking to develop suitable new decontamination solutions and equipment for shipboard and port facilities applications, which will be both more effective and less corrosive, as well as more environmentally friendly.

Warning and Reporting

The technical areas of detection and hazard assessment come together in the area of warning and reporting. Once agents have been detected, this information must be managed, warning provided to those who need it, and a picture of the threat provided to the commander on the scene.

The **JWARN** is the information management tool that will pull together the data generated by all of the detection systems discussed above and integrate that information into a picture of the chemical and biological threat for the ship's commander and the outside world. A single screen will report status and alarm from each of the detectors on board, and hazard prediction models imbedded in the JWARN system architecture (see Figure 8) will allow on-site analysis of the situation for contamination avoidance or mitigation in near real time with reduced manpower requirements. This will be a decision aid that will give the commander on the scene better situational awareness, and allow coordinated response and analysis by other units afloat and ashore. The JWARN will provide joint forces with a comprehensive analysis and response capability to minimize the effects of hostile nuclear, biological, and chemical (NBC) attacks/accidents. It will provide the operational capability to employ NBC warning technology, which will collect, analyze, identify, locate, report, and disseminate NBC threats. JWARN will be compatible and integrated with joint service command, control, communications, computers, intelligence, and interoperability systems. The JWARN will be located in command and control centers at the appropriate level defined by each of the services and employed by NBC defense specialists and other designated personnel.

JWARN will transfer data automatically from and to the actual detector/sensor and provide commanders with analyzed data for decisions for disseminating warnings down to the lowest level on the battlefield. It will provide additional data processing, production of plans and reports, and access to specific NBC information to improve the efficiency of limited NBC personnel assets.

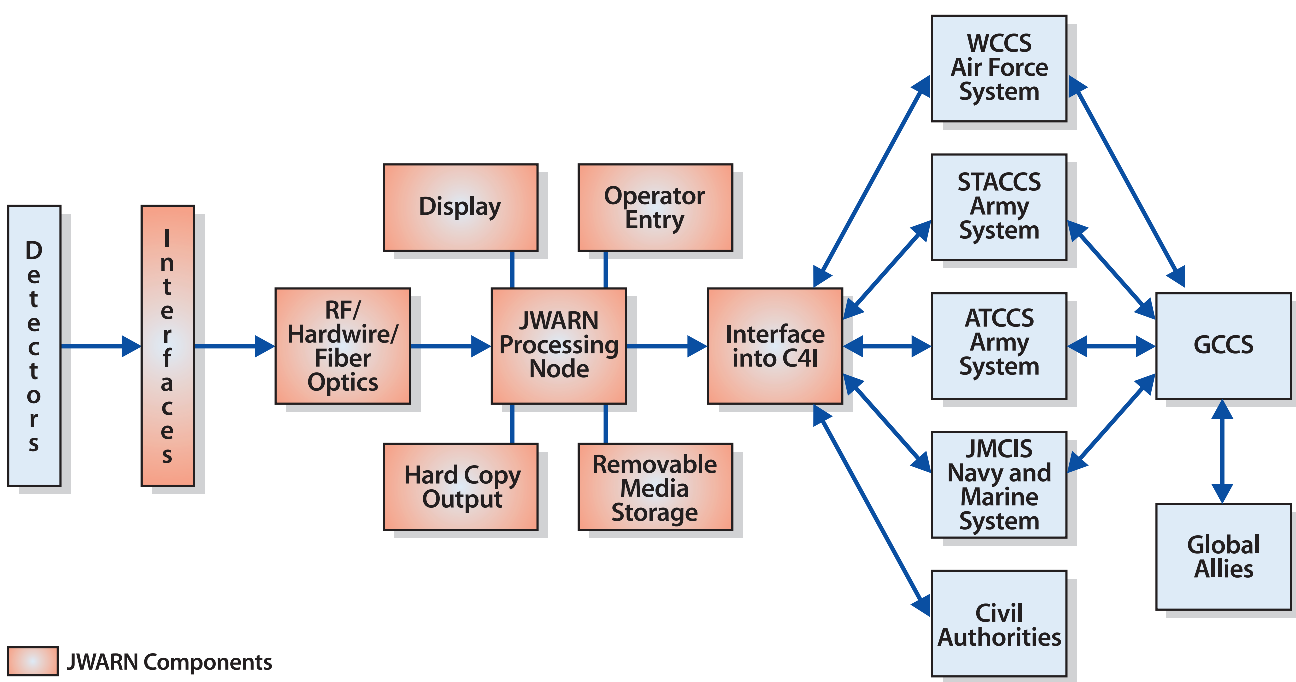

Figure 8—Joint Warning and Reporting Network (JWARN) Functional Block Diagram

THINGS TO COME

With the proliferation of chemical and biological industrial technology around the world, the nature of the CBW threat continues to evolve. The CBW defense response to this threat will continue to evolve as well. Chemical detection will have to adapt to a wider array of threats such as toxic industrial chemicals and novel threat agents developed by some industrial countries enter the arsenals of terrorists and rogue states. Advances in biotechnology raise the spectre of bio-engineered weapons expressly designed to defeat detection and protection equipment already fielded.

Development of collective protection equipment will have to stay ahead of new-threat agents designed to defeat traditional charcoal filters, and likewise, individual protection gear will have to adapt to new threats while producing less of a logistics burden, as well as providing better support to the user by being more comfortable to wear for longer periods.

Development of detection technologies will continue to move towards integrating suites of detectors, while also reacting to emerging threats. The ultimate goal of a JCBUD may be attainable for point detection, but will still need to be coupled to standoff detection as well as intelligence, remote sensing, and integrated warning and reporting. A vigorous defense in depth through the integration of many technologies to advance individual and collective protection, detection, warning and reporting, and decontamination will continue to be the response mounted against chemical and biological weapons as the future surface combatant becomes a reality.

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Dr. Daniel C. Driscoll graduated from Syracuse University in 1979 with a B.S. in physics. After graduate studies at Northeastern University and 3 years working in industry in the area of thin film deposition and characterization, he resumed graduate studies at Syracuse, receiving an M.S. in physics in 1986 and a Ph.D. in chemical physics in 1987. He was an Office of Naval Technology postdoctoral fellow at the Naval Research Laboratory for 3 years, during which time he worked in the areas of plasma and combustion chemistry. He joined NSWCDD in 1991 and works in the Systems Research and Technology Department; his main area of effort has been the development of sensors for chemical warfare agents. He was involved in the development and testing of IPDS. He is currently the technical point of contact for the Navy in the JSLSCAD Program, a joint program to develop, test, and field a passive IR remote detector for CW agents. If successful, this program will provide a standoff chemical agent detection capability to surface combatants and overseas port facilities.

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Mr. Robert A. Fitzgerald, Jr., graduated from Virginia Tech in 1984 with a B.S. degree in mechanical engineering after spending 4 years active duty in the U.S. Air Force (1976-1980). After graduation, he worked at the U.S. Army Belvoir Research, Development and Engineering Center, Ft. Belvoir, Virginia, as a project engineer in tactical bridging programs until 1988. Bob joined NSWCDD Systems Research and Technology Department in 1988 as the group leader for the CPS group. In 1989, he became the group leader for the chemical detection systems group and led the team in the development and testing of the Improved Point (Chemical Agent) Detection System (IPDS). He is currently the chemical detection section head and manages his section's support of all Navy chemical detection programs including JCAD, SALAD, Ship ACADA, JSLSCAD, and JWARN.